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Delias butterflies (Lepidoptera, Pieridae) cohabiting in the highlands of New Guinea Island

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Abstract *Delias* is one of the genera belonging to Pieridae, which is well known for bright wing markings considered as aposematic colors. A list of *Delias* butterflies cohabiting in some localities of the highlands of New Guinea Island (New Guinea) is presented, to demonstrate that their marked diversification and cohabitance are general features of this genus in that region. The mechanism of their remarkable speciation has been considered to be allopatric and we demonstrate it by presenting a typical example. Such distinct differences presented as a typical example, however, have not been observed in the mountains of Southeast Asia. Therefore, we suggest that other mechanisms, which remain unclarified, underlie the peculiar diversification of *Delias* butterflies and the maintenance of their cohabitance in New Guinea.

Key words Biodiversity, cohabitance, *Delias*, diversification, Irian Jaya, New Guinea, Pieridae, Speciation.

Introduction

Butterflies of the genus *Delias* Hübner, 1819 are widely known to lepidopterists due to the bright and varied markings on the underside of their wings. They are distributed from India to New Caledonia, mainly in Southeast Asia and New Guinea. Yagishita *et al.* (1993) identified 216 species based mainly on the classification of Talbot (1928-1937). New taxa have continued to be described (Roepke, 1955; Jumalon, 1975; Yamamoto & Takei, 1982; Orr & Sibatani, 1985, 1986; Morinaka *et al.*, 1993; Mastrigt, 1996, 2000; Morinaka & Nakazawa, 1997, 1999; Lachlam, 2000). The hosts of the larvae are known to be mistletoes (Loranthaceae and the related family Santalaceae (Semper, 1886-1892; Talbot, 1928-1937; McCubbin, 1971; Parsons, 1999)), although the larval hosts remain mostly unknown in the highlands of New Guinea.

Since Finn's experiments (1895), *Delias* butterflies are considered to be poisonous, which may have originated from their larval host (Parsons, 1999), and their wing markings aposematic (Yata, 1981; Corbet & Pendlebury, 1992; Parsons, 1999). In fact, many butterflies and moths have been reported to be their mimic (Talbot, 1928-1937; Corbet & Pendlebury, 1992; Parsons, 1999).

Morinaka (1993) reported that in a two-day observation only, 16 species of *Delias* butterflies flew together in a small creek of the river Úwe (2,000 m altitude (alt.)) in Baliem Valley.

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Parsons (1999) reported that as many as 15 species flew together. We also frequently observed similar gatherings in other localities in the highlands (more than 1,800 m alt.) of New Guinea. In this paper, we report species of *Delias* butterflies, which were observed to fly together in New Guinea including an incidental observation of their oviposition, and demonstrate the expansion of their speciation and that their cohabitance is almost limited to New Guinea.

Materials and methods

Species

Species names used in a list (see method 1) are based on Morinaka *et al.* (1991, 1993), Yagishita *et al.* (1993), Mastrigt (2000) and Lachlan (2000).

Method

1. We listed species of *Delias* butterflies in all localities of New Guinea Island where we observed *Delias* butterflies to fly together for two fine days or more (except Nalca) in 1997–1998.

2. The total and endemic numbers of *Delias* species found between New Guinea and Southeast Asian Islands ($>100{,}000$ km^2) including the Australian Subcontinent were counted with species names based on Yagishita *et al.* (1993) and compared.

Results

1. The species and the localities in which they were observed flying together are as follows.

West part of Kubor Mts (144°10′–144°20′E, 6°00′–6°10′S; 2,000–2,200 m alt.)

3rd and 5th of August 1997 (Fig. 1)

Species identified in a creek:

D. hypomelas, *D. microsticha*, *D. hagenensis*, *D. nais*, *D. iltis*, *D. leucias*, *D. callima*, *D. clathrata*, and *D. meeki*.

South slope of Mt Hagen (144°00′–144°10′E, 6°10′–6°20′S; 2,200–2,400 m alt.)

4th and 7th of August 1997

Species identified in a mountainous road and a creek:

D. hypomelas, *D. microsticha*, *D. aroae*, *D. flavissima*, *D. hagenensis*, *D. hallstromi*, *D. gilliardi*, *D. nais*, *D. iltis*, *D. leucias*, *D. mira*, and *D. meeki*.

Nalca (139°50′–140°00′E, 4°20′–4°30′S; 2,400–2,600 m alt.)

2nd of September, 1997 (Figs 2, 5)

Species identified in a mountainous road and a creek:

D. hypomelas, *D. microsticha*, *D. fascelis*, *D. oktanglap*, *D. approximata*, *D. yabensis*, *D. frater*, *D. carstensziana*, *D. nais*, *D. luctuosa*, *D. awongkor*, *D. callista*, *D. hapalina*, *D. leucias*, *D. rosamontana*, *D. alepa*, *D. wollastoni*, *D. reopkei*, *D. klossi*, and *D. neagra*.

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Figs 1–2. Sites of *Delias* butterflies observed flying together. 1. A creek of western part of Kubor Mts (2,000–2,200 m alt.). 2. A creek near Nalca from Aipomek (2,400–2,600 m alt.).

Figs 3–4. Gathering of *Delias* butterflies in a creek near Pass Valley (1,800–2,000 m alt.). 3. Gathering of *D. toxopei* (dominant species there). Other butterflies (Lycaenidae sp.) and moth (*Milionea* sp.) were also observed. 4. *Delias* sp. of the *aroae* sub-group (left) and *D. klossi* (right) sucking water on a river bed.

Fig. 5. Camp site on a ridge of a mountain from Aipomek to Nalca (2,000–2,200 m alt.).

Fig. 6. Research team studyng insects (including *Delias* butterflies) in 1998 (Danau Habbema in the background; about 3,000 m alt.). From left, Dr Seiki Yamane, Mr Katsumi Eguchi, Sadaharu Morinaka and Ida Ketut Ginarsa.

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Yohosin (139°00′-139°10′E, 4°10′-4°20′S; 2,100-2,300 m alt.)

28th-30th of July, 1998

Species identified in a mountainous road and a creek:

D. hypomelas, *D. argentata*, *D. microsticha*, *D. fascelis*, *D. approximata*, *D. antara*, *D. germana*, *D. carstensziana*, *D. nais*, *D. zebra*, *D. luctuosa*, *D. flavistriga*, *D. callista*, *D. leucias*, *D. rosamontana*, *D. alepa*, *D. wollastoni*, *D. klossi*, and *D. neagra*.

Pass Valley (139°00′-139°10′E, 3°50′-4°00′S; 1,800-2,000 m alt.)

27th-29th of April, 1997 and 28th-29th of April, 1998 (Figs 3-4, 13)

Species identified in a mountainous road and a creek:

D. hypomelas, *D. argentata*, *D. microsticha*, *D. fascelis*, *D. oktanglap*, *D. approximata*, *D. balimensis*, *Delias inopinata*, *D. antara*, *D. germana*, *D. carstensziana*, *D. toxopei*, *D. catisa*, *D. nais*, *D. zebra*, *D. flavistriga*, *D. callista*, *D. hapalina*, *D. leucias*, *D. rosamontana*, *D. alepa*, *D. wollastoni*, *D. autumnalis*, *D. klossi*, *D. walshae*, and *D. neagra*.

Road from Ibele to Danau Habbema (138°40′-138°50′E, 4°00′-4°10′S; 2,400-3,000 m alt.)

27th and 30th of April, 1998 (Figs 6, 13)

Species identified in a mountainous road:

D. argentata, *D. balimensis*, *D. approximata*, *D. antara*, *D. germana*, *D. leucobalia*, *D. carstensziana*, *D. toxopei*, *D. catisa*, *D. zebra*, *D. luctuosa*, *D. flavistriga*, *D. leucias*, *D. rosamontana*, *D. wollastoni*, and *D. klossi*.

Behavior of oviposition observed

One of the authors, Ginarsa, observed two female *Delias* butterflies (maybe *D. microsticha* and a species of the *aroae* sub-group) ovipositing on the underside of the leaves of the same mistletoe on the road from Ibele to Danau Habbema at 13 : 00 pm on 28th October 1997.

2. Relevant data are shown in Table 1. The total and endemic numbers of *Delias* species cohabiting in New Guinea are 105 and 97, respectively. They are both significantly higher than those from other islands of Southeast Asia and the Australian Subcontinent. The ratio of the number of endemic species to the total number of species from New Guinea is 92.4%, which is also markedly higher than that from other islands.

Discussion

In this paper, we listed species found in the highlands of New Guinea which we could confirm to fly together for one day or more during our trips from 1997-1998 and counted the total and endemic numbers of *Delias* species in each island. In another case, we have identified five or more species of *Delias* butterflies flying together for one or two hours at many places, for example in Wau (146°40′-146°50′E, 7°20′-7°30′S; 1,800-2,200 m), Mt Wilhelm (145°00′-145°10′E, 5°10′-5°20′S; 2,600-3,000 m), Mt Giluwe (143°50′-144°00′E, 5°5′-6°00′S; 2,600-3,000 m), Mt Laya (142°40′-142°50′E, 5°30′-5°40′S; 1,800-2,200 m), Korupun (139°30′-139°40′E, 4°20′-4°30′S; 2,200-2,600 m), and Mbuwa (138°20′-138°30′E, 4°10′-4°20′S; 2,000-2,400 m).

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Parsons (1991) listed 32 species from Bulolo-Wau Valley (Morobe Province (Prov.)) and also many species were reported from Kerowagi (Chimbu Prov.), Wabag (Enga Prov.), OK Tedi (Western Prov.) Ambisibil, Langda, Tiom, Mulia, Ilu, Tembagapura, Mapia, Timepa and Arfak Mts in Irian Jaya (Gerrits and Mastrigt, 1993; Yagishita *et al.*, 1993; Mastrigt, 1996, 2000; Parsons, 1999; Lachlan, 2000). We suppose that many of them cohabited. We obtained information about their cohabitance from some people who collected or observed *Delias* butterflies in the field. As a result, we learned that at least five species flew together in some localities of the above-mentioned areas.

In Southeast Asia in contrast, although many species of *Delias* butterflies are known, gathering of many species at a site has not been reported. Generally, one to three species were observed to fly together in both the lowlands and highlands of Southeast Asia. Moreover, the total and endemic numbers of *Delias* species from Southeast Asia and the Australian subcontinent reported are not so large when compared with those from New Guinea (Table 1). Our data indicate that a marked diversification of *Delias* species occurred and is particularly maintained in New Guinea even if the number of species will be nomenclaturally decreased due to their taxomic treatments.

The undersides of wings of *D. callista*, *D. luteola* (which was separated from *D. callista*, Yagishita *et al.*, 1993), *D. wollastoni* and *D. autumnalis* from Pass Valley and Ibele or its vicinities are shown in Figs 7–12. These two localities are separated approximately 30–40 km from each other by Baliem Valley lying between them (Fig. 13). There are distinct differences in the wing markings of these species, although there are other species in both localities having almost the same wing markings. We consider that the geographical separation (vicariance) prevented mutual gene flow and led to species diversification. It is not the only reason, however, because such distinct differences in wing markings of two species or more have not been observed in the mountains of Southeast Asia, although the same land features, that is, mountains separated by deep valleys, are also observed there.

The larval hosts are known for only four species of *Delias* from the highlands of New Guinea: *D. iltis* and *D. luctuosa* feed on the same species of mistletoe, *Amyema wichmannii* (Parsons, 1999), and their early stages are known. The larvae of *D. meeki* and *D. niepelti* were reported to feed on *Glochidion* sp. and *Helicia sleumerana*, respectively, which are not phylogenetically close to mistletoes (Parsons, 1999). However, these records require confirmation (Parsons, 1999) because it is not clear whether these trees are indeed the hosts.

Table 1. Total and endemic numbers of *Delias* species found between New Guinea and Southeast Asian Islands ($>100{,}000$ km^2) including the Australian Subcontinent based on Yagishita *et al.* (1993).

	Areas (km^2)	No. of species	No. of species/ 10,000 km^2	No. of endemic species	Ratio (%) of endemic species/total species
Luzon	104,687	8	0.76	2	25.0
Borneo	743,325	9	0.12	2	22.2
Sumatera	473,600	9	0.16	1	11.1
Jawa	126,520	9	0.71	3	33.3
Sulawesi	189,070	9	0.47	6	66.7
New Guinea	**828,800**	**105**	**1.27**	**97**	**92.4**
Australia	7,682,292	7	0.01	2	28.6

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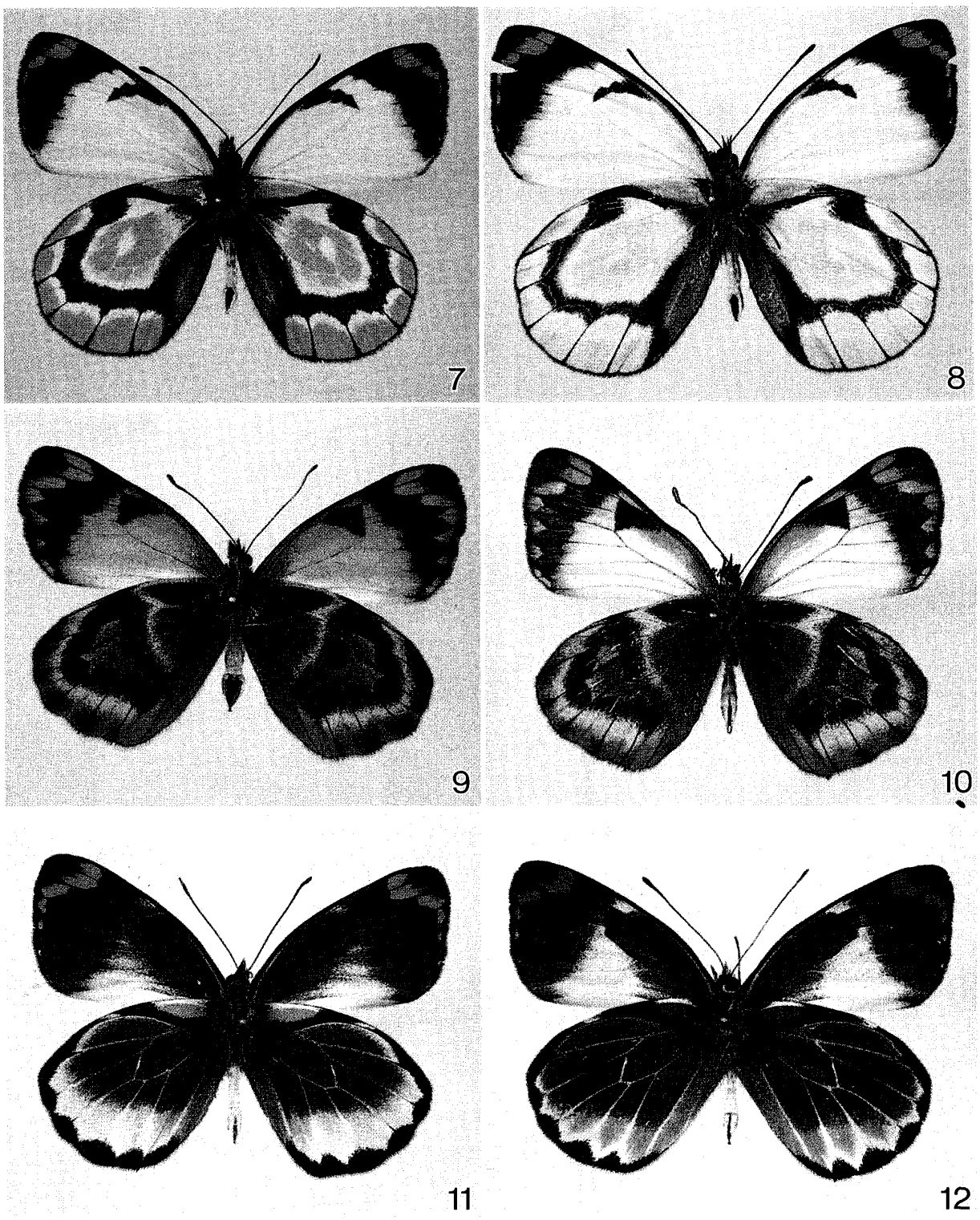

Figs 7–12. Distinct differences of same (or phylogenetically closest) species of *Delias* butterflies. Butterflies on the left side are from Pass Valley and those on the right side are from Ibele or its vicinites. 7. *D. callista* (forewing length (Fl) 28 mm). 8. *D. luteola* (separated from *D. callista* (Yagishita *et al.*, 1993), Fl 31 mm). 9–10. *D. wollastoni* (Fl: left 28 mm, right 27 mm). 11–12. *D. autumnalis* (Fl: left 28 mm, right 29 mm).

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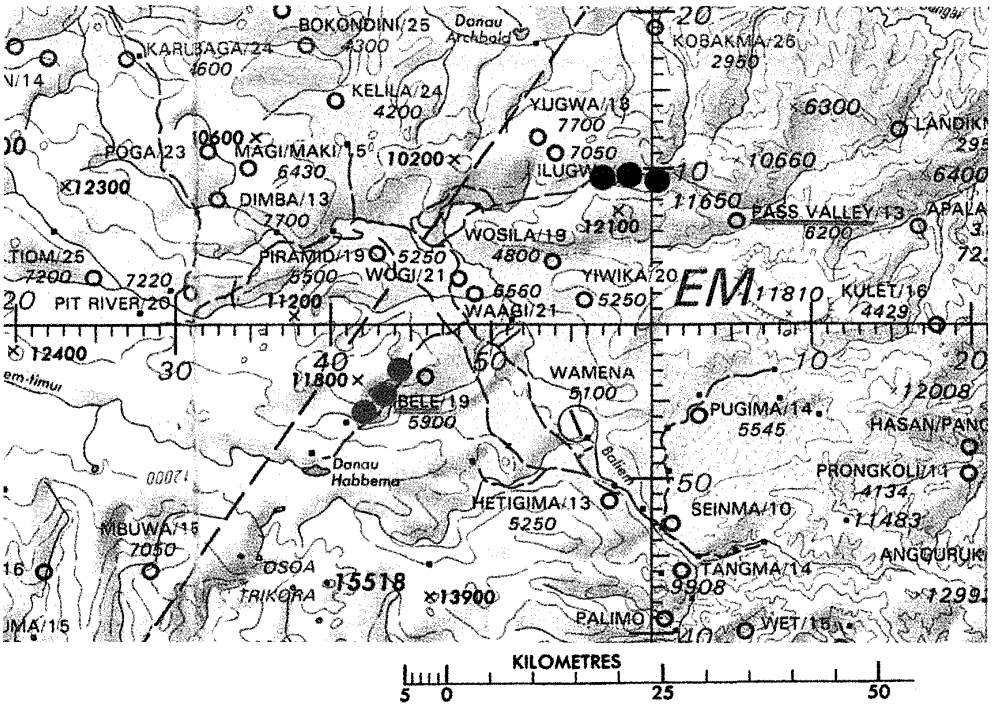

Fig. 13. Collection sites in Pass Valley and along the road from Ibele and its vicinities. Yellow color indicates 7,000 feet or more above sea level. Green closed circles indicate the site in Pass Valley and red closed circles indicate the sites near Ibele. (Cited from Operational Navigation Chart: M-13, ed. 6, 1982, Aeronautical Information Section Headquarters Support Command, RAAF, Victoria Barracks Melbourne, 3004, Victoria Australia and refered to Nelles Maps "Irian Jaya & Maluku", Nelles Verlag GmbH, D-80935 München.)

Ginarsa's observation suggests that the larvae of at least two species feed on the same species of mistletoe (name of the mistletoe could not be identified). It is supposed that their larval hosts are generally mistletoes as in the Oriental region. Marked speciation of mistletoes is not known in New Guinea (Danser, 1933; Barlow, 1974). Based on this information, we consider that the marked speciation of *Delias* butterflies in the highlands of New Guinea did not result from the speciation of mistletoes.

In this paper, we have shown a typical example of the allopatric speciation of *Delias* butterflies; however, we emphasize here that it is just one of the mechanisms which led to the generation of these peculiar features. How and why have such cohabitance and marked diversification occurred particularly in New Guinea ? How are they maintained, and are they necessary or incidental ? These remain to be clarified in future investigations, results of which will elucidate the functions of biodiversity.

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摘　　要

ニューギニア島高地で同所共存するカザリシロチョウ (森中定治，船橋勝幸，I. K. Ginarsa，宮田　正，田中健治)

ニューギニア島高地において同所共存するカザリシロチョウの種類が複数の地区から報告され，幾つかの知見を踏まえて，ニューギニア島高地に生息するカザリシロチョウは少なくとも5種以上の同所共存が通常の生態であることが見いだされた．一方，東南アジアにおいては，高地でも低地でも単独か2-3種の共存が通常である (一部に例外的な地域はあるが限られる)．さらに，ニューギニア島高地と東南アジアの島嶼 (>100,000 km^2) に生息するカザリシロチョウの総種数と固有種種数との比較 (Table 1) から，ニューギニア島に生息するカザリシロチョウが特に著しく多種化したことが示された．

それらの種分化機構については一般的に地理的な隔離によると考えられている．我々はその種分化機構について，Baliem Valley を挟む2地域の同種あるいは姉妹種の形態学的比較 (Figs 7-12) から地理的な隔離が遺伝子の交流を妨げ，種分化を引き起こしていることを複数種の具体的事例によって明らかにした．しかしながら，このような分断された地形 (Fig. 13) はニューギニア島高地のみならず東南アジアの山岳地帯にも見られるが，それらからは複数種のこのような同種間の著しい斑紋の差異は知られていない．それゆえ，地理的な隔離 (生物地理学的分断) だけでこのような著しい多種化が引き起こされ，維持されているとは考え難い．ニューギニア島高地における幼生期の生態は殆ど知られていないが，幾つかの種において幼虫がヤドリギを食すことが確認されており，ニューギニア島高地においても一般にそのホストはヤドリギと推察される．ヤドリギがニューギニア島において特に著しく多種化したという報告はなく，ホストの特別な種分化に付随した特殊な現象とも考え難い．ニューギニア島に生息するカザリシロチョウにほぼ固有の現象である著しい種分化とそれらの同所共存が何故起こったのか，どのような機構でそれが維持されているのか，それはその地にたまたま偶然起こったことなのか，それともその地ではそうならねばならない必然的な理由があるのか，この多種化およびその共存機構へのさらに深い探求は，生物多様性の成因解明にもつながる興味深くかつ重要なテーマであると考えられた．

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